Synthesis of methane observations across scales in an urban domain: Strategies for deploying a multi-tiered observing network.

Jet Propulsion Laboratory
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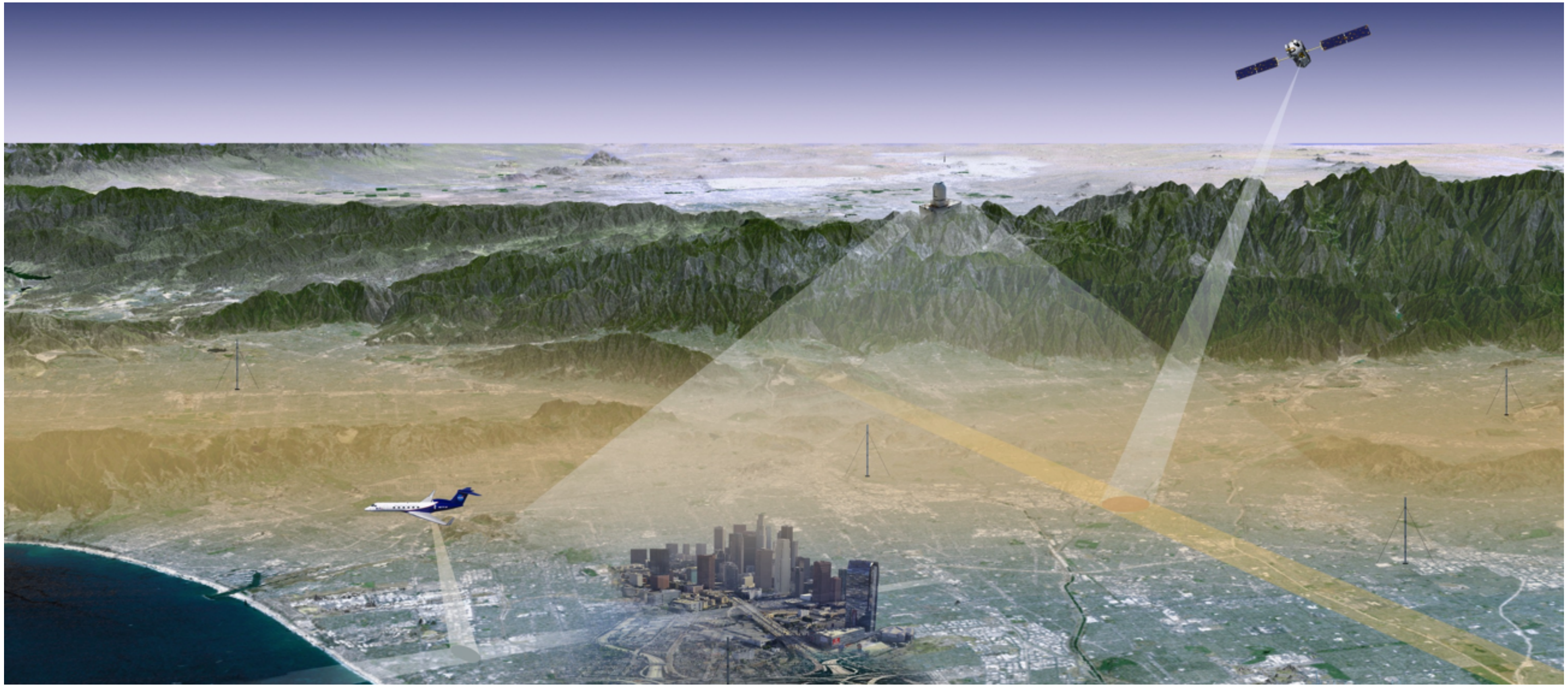

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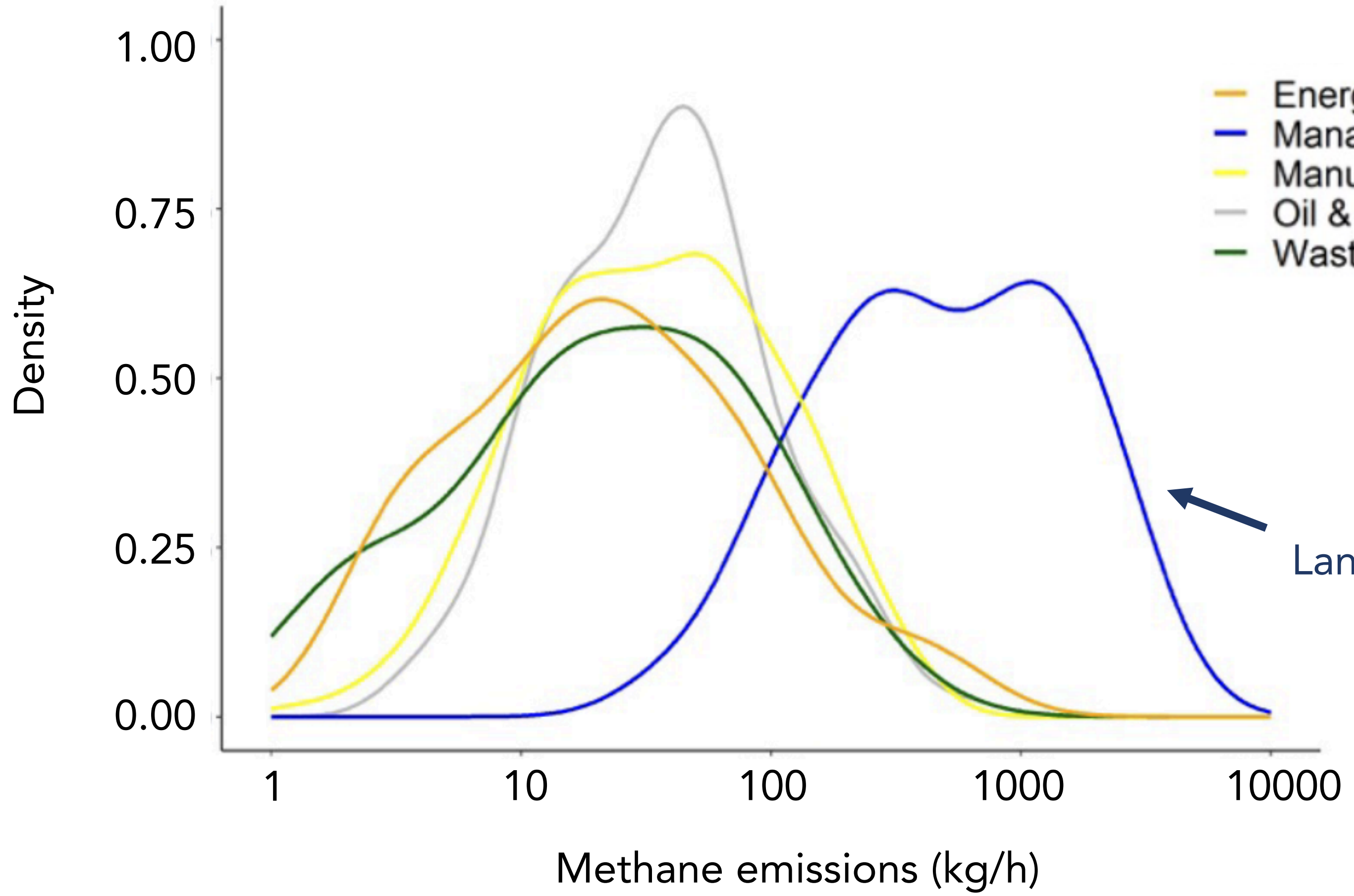
A large component of the total anthropogenic methane budget may be due to relatively few "fat-tailed" emitters.

Log distribution of point source emissions from the California Methane Survey

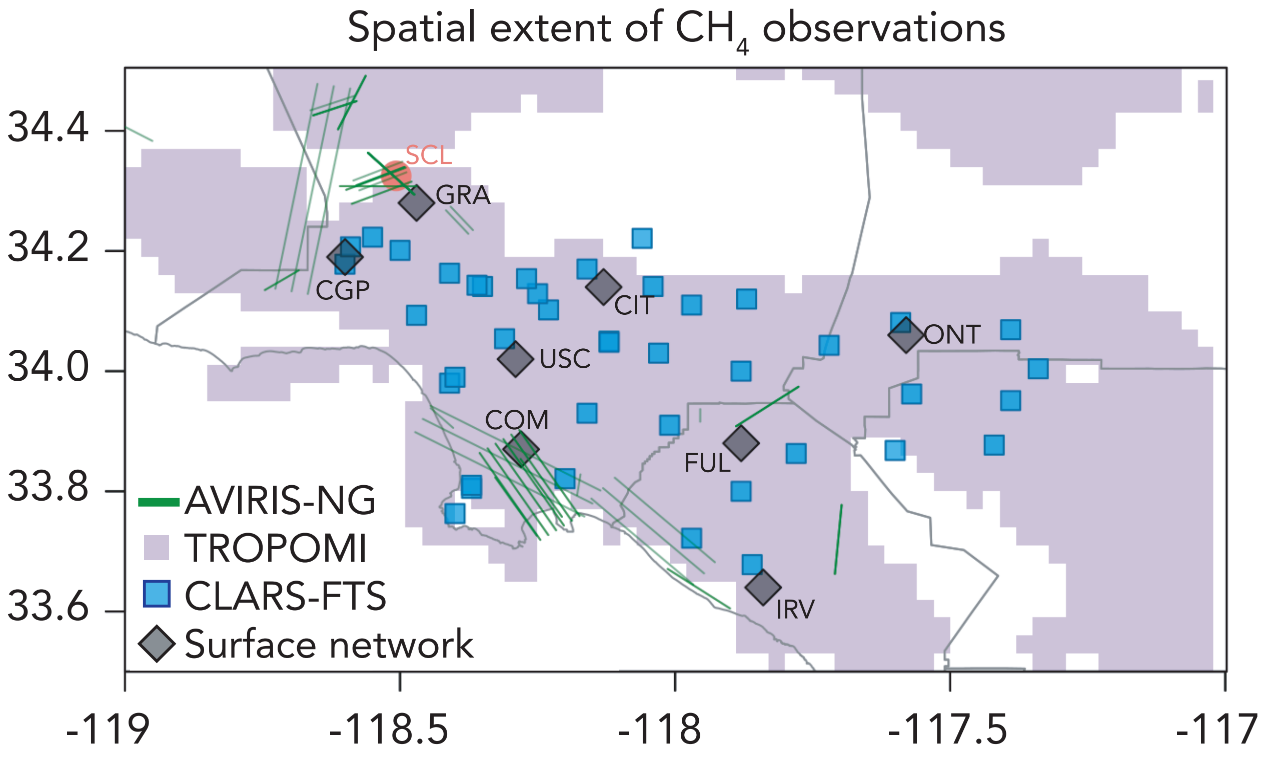


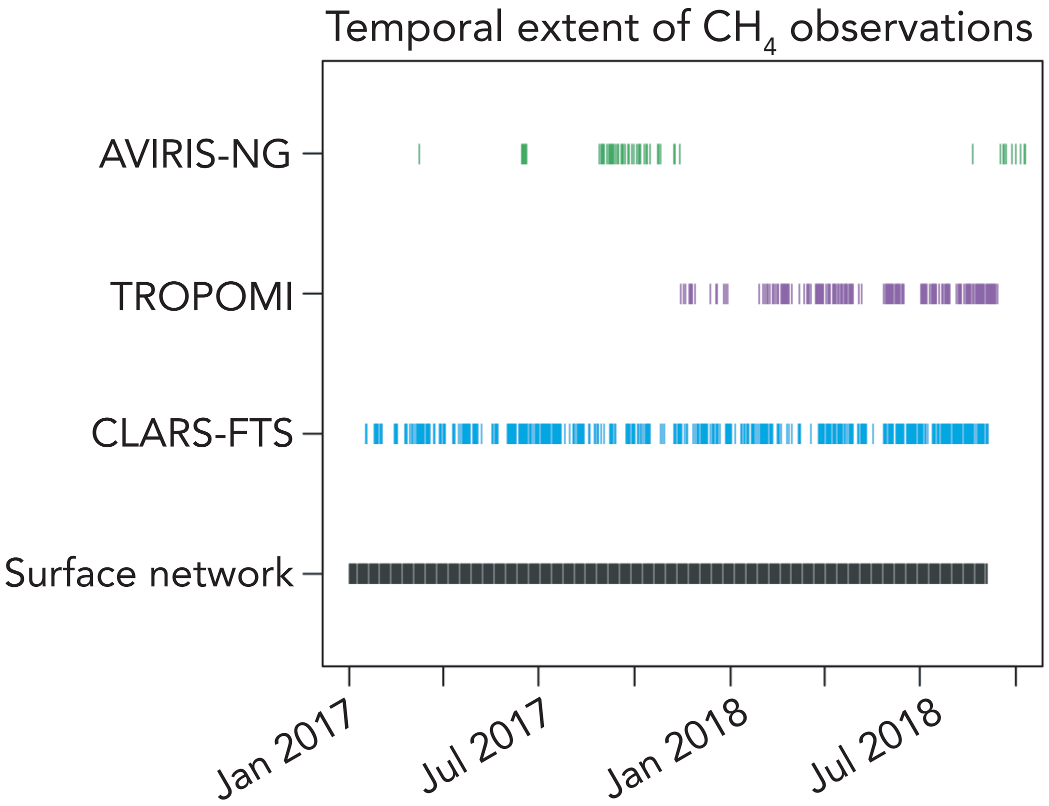
Landfills are largest single point source

Duren et al. (2019)

Monitoring/mitigation of methane emissions will require combining multiple observations: example in Los Angeles.

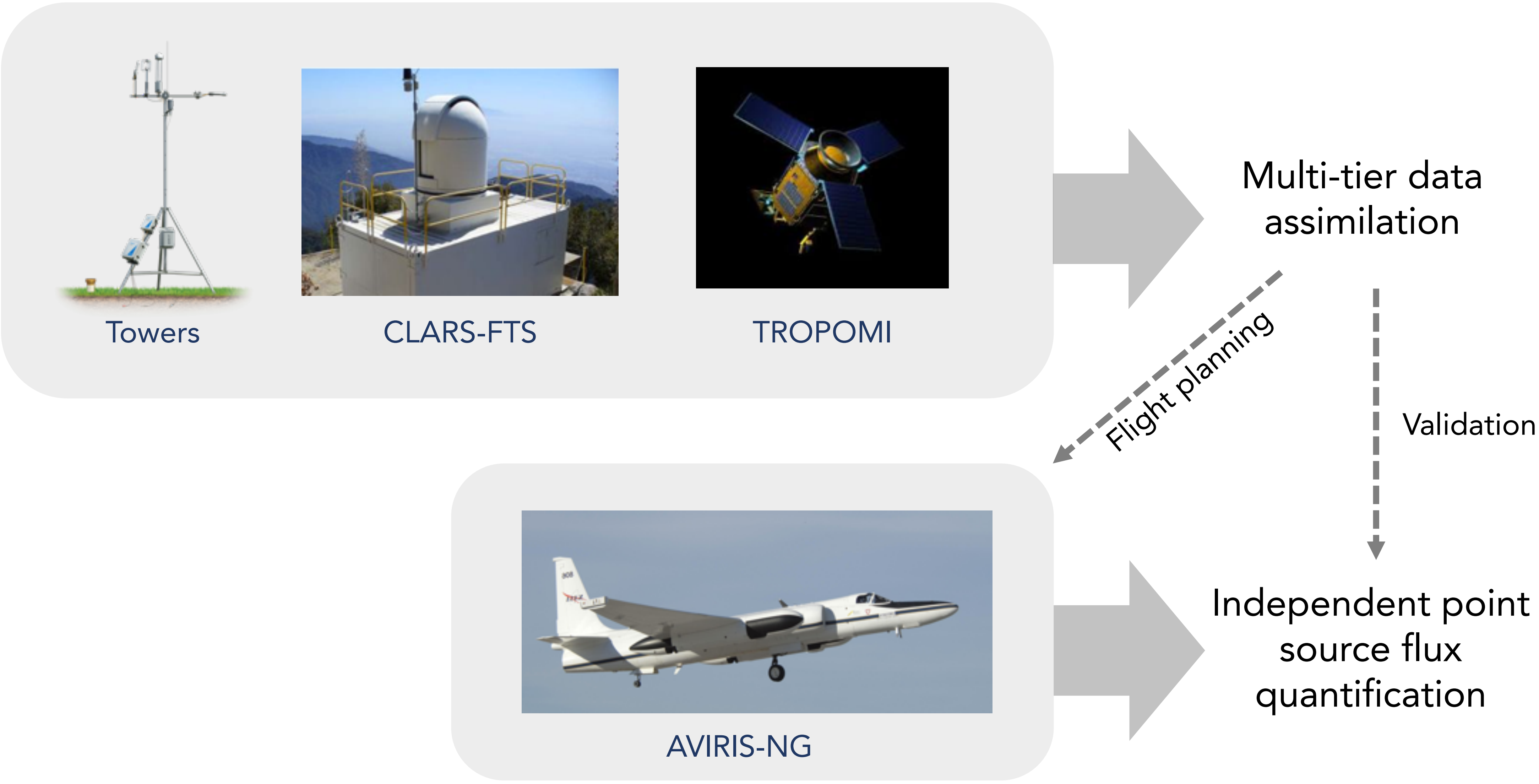
Spatial and temporal availability of CH_4 observations during study period





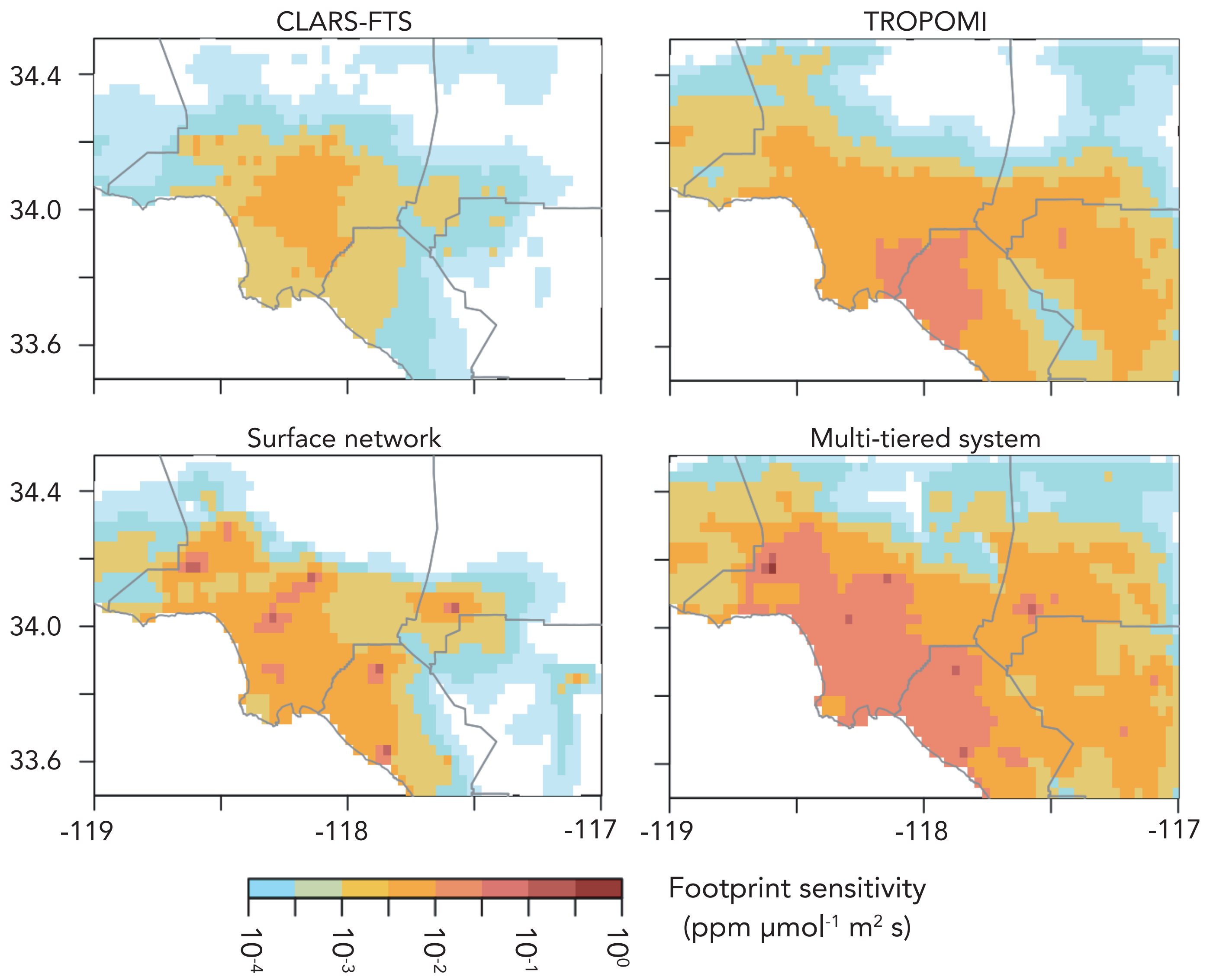
How do we leverage all this information into one data system?

How do we combine these data streams together?



Total basin sensitivity to emissions depends on type of instrument and spatial/temporal density

Average overpass footprint sensitivity of CH_4 observing system



Footprints ($\partial\mathbf{F}/\partial\mathbf{x}$) simulated using HRRR-STILT tracer-transport model

Though TROPOMI is less sensitive to surface emissions, it has greater spatial coverage throughout the basin.

We use a Gaussian Bayesian inverse system to relate derive estimates of emission rates.

Derived via STILT

$$\mathbf{h}_i = \left(\frac{\partial y_i}{\partial \mathbf{x}}\right)^T$$

Observation

Simulation

Error

$$y_i = \mathbf{h}_i \cdot \mathbf{x} + \epsilon$$

Put everything together into a cost function that balances a fit to the observations and prior information

$$J(\mathbf{x}) = \underbrace{(\mathbf{y}-\mathbf{Hx})^T\mathbf{R}^{-1}(\mathbf{y}-\mathbf{Hx})}_{\text{Model/Data mismatch}} + \underbrace{(\mathbf{x}-\mathbf{x_A})^T\mathbf{S}^{-1}(\mathbf{x}-\mathbf{x_A})}_{\text{Prior emission inventory}}$$

R, S: error covariance matrices

Minimizing cost function gives "optimal" answer ($\hat{\mathbf{x}}$):

$$\hat{\mathbf{x}} = \mathbf{x_A} + \mathbf{G}(\mathbf{y}-\mathbf{Hx})$$

where

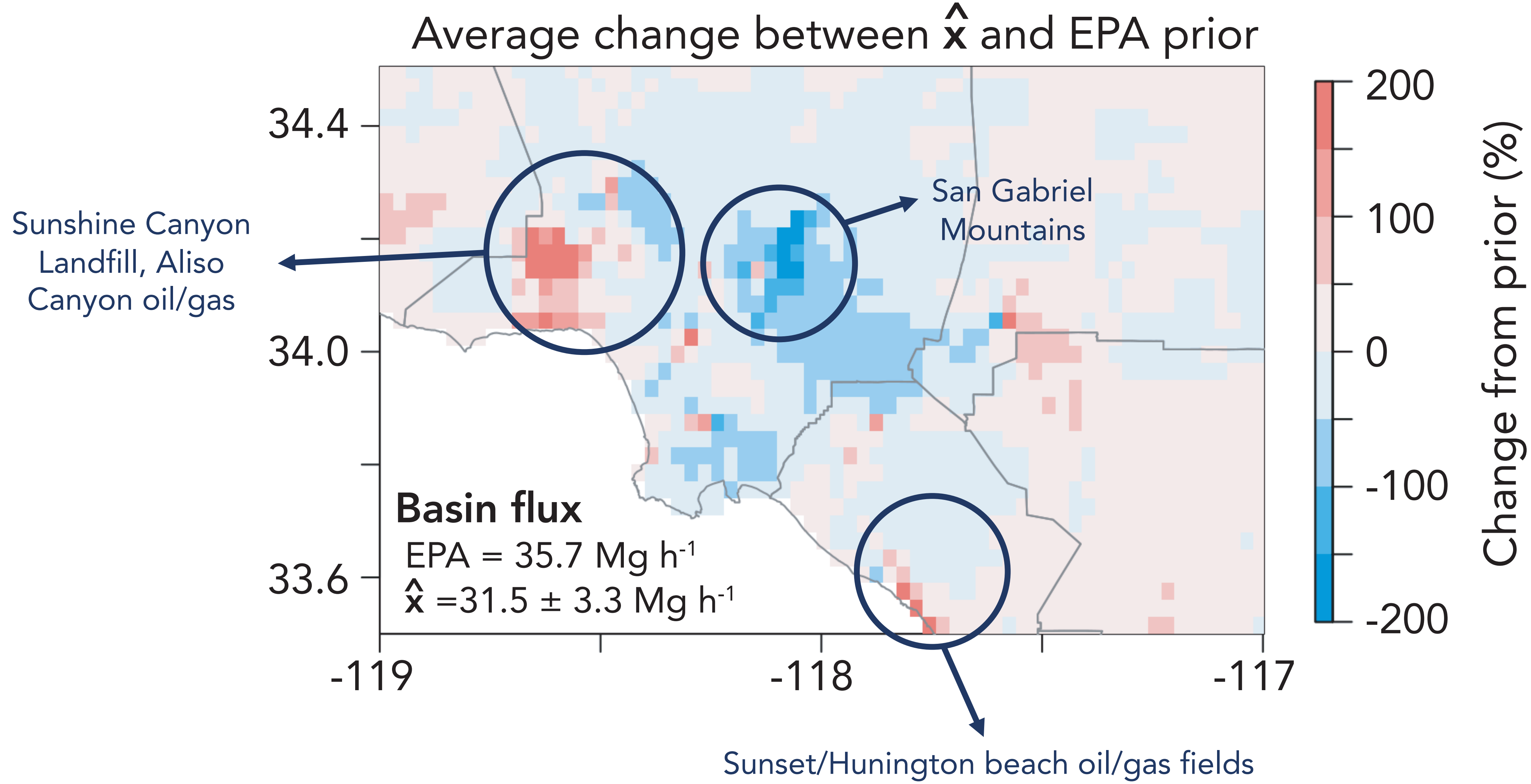
$$\mathbf{G} = \frac{\partial \hat{\mathbf{x}}}{\partial \mathbf{y}} = \mathbf{S_A}\,\mathbf{H}^T(\mathbf{HS_AH}^T + \mathbf{R})^{-1}$$

Gain matrix

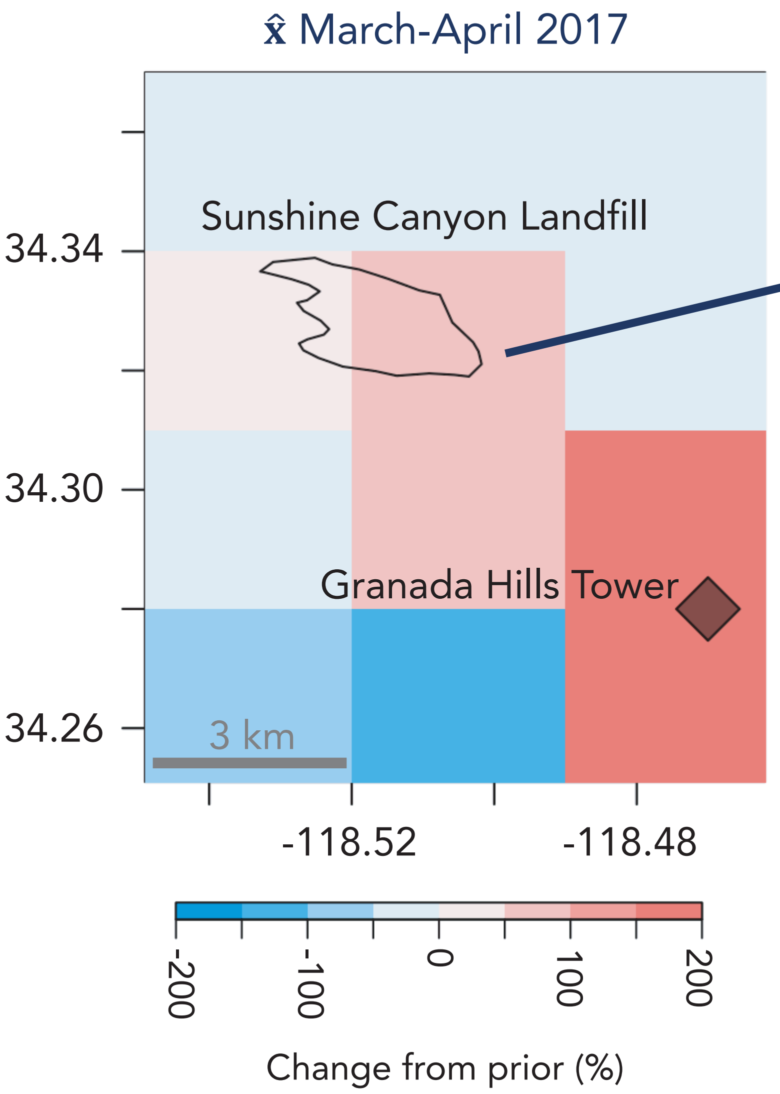
$$\mathbf{A} = \frac{\partial \hat{\mathbf{x}}}{\partial \mathbf{x}} = \mathbf{GH}$$

Averaging kernel

All observations and footprints can be brought together in an inverse modeling framework to optimize gridded flux emissions:

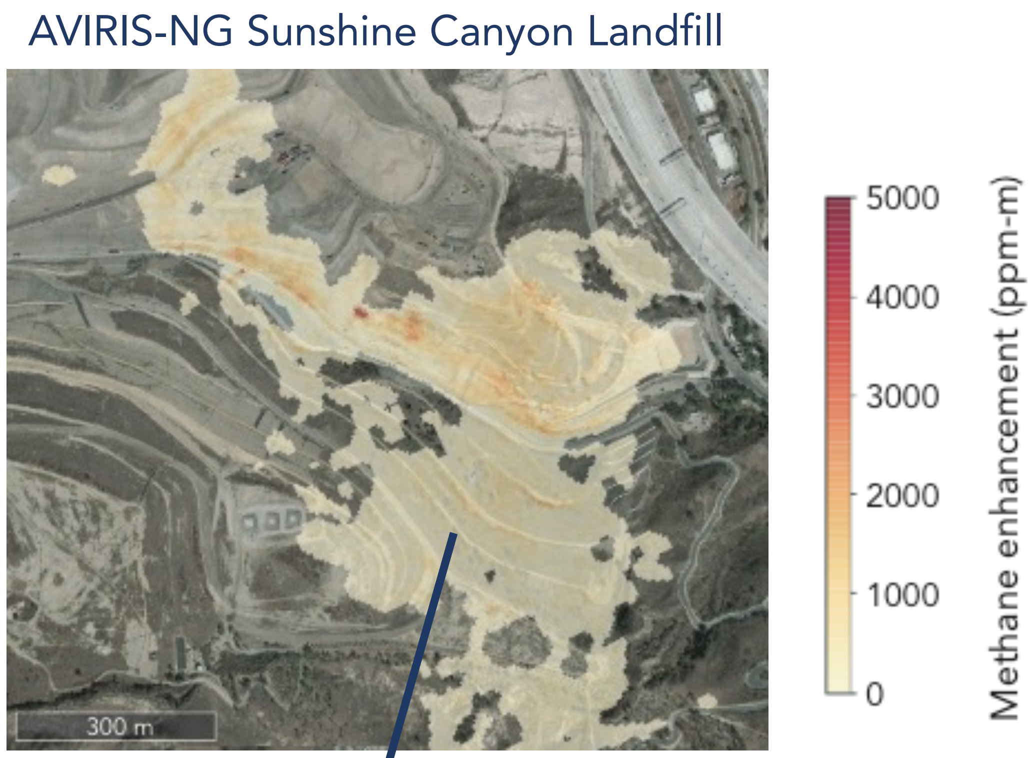


We can use the inverse result to target specific areas.
Case study: Sunshine Canyon Landfill



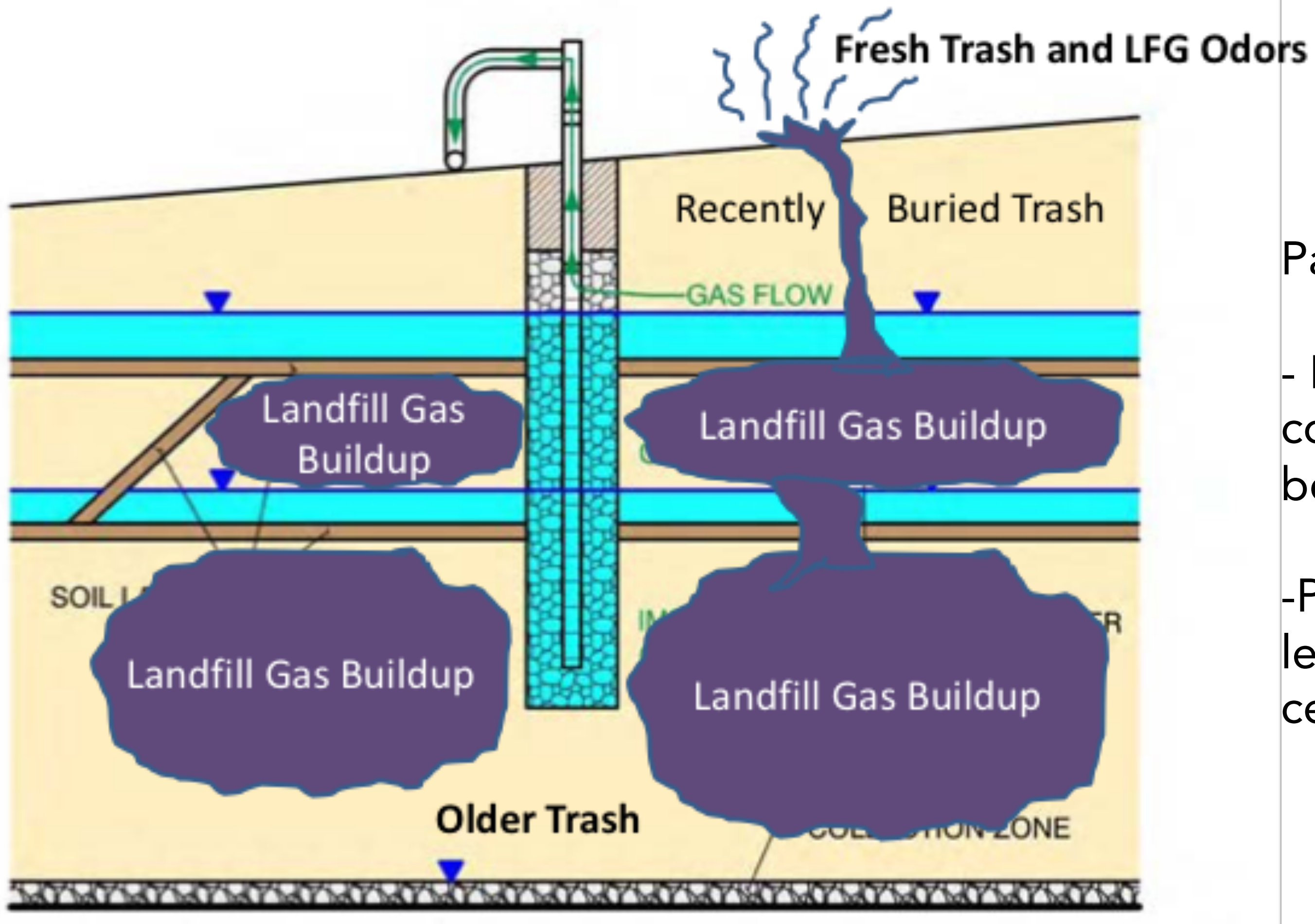
Emissions around Sunshine Canyon higher than EPA prior early in study period

This tells us where to go fly AVIRIS-NG



Massive methane plumes emanating from intermediate slopes. **So we called them on the phone…**

JPL shared the AVIRIS-NG data with the Sunshine Local Enforcement Agency.
They determined that the plumes originated from past management practices.



Past practice:

- For every "lift" of trash, 9 inches of compacted soil was placed as cover before next lift was added.

-Problem: this did not allow for leachate to percolate to bottom of cell, causing gas buildup near surface.

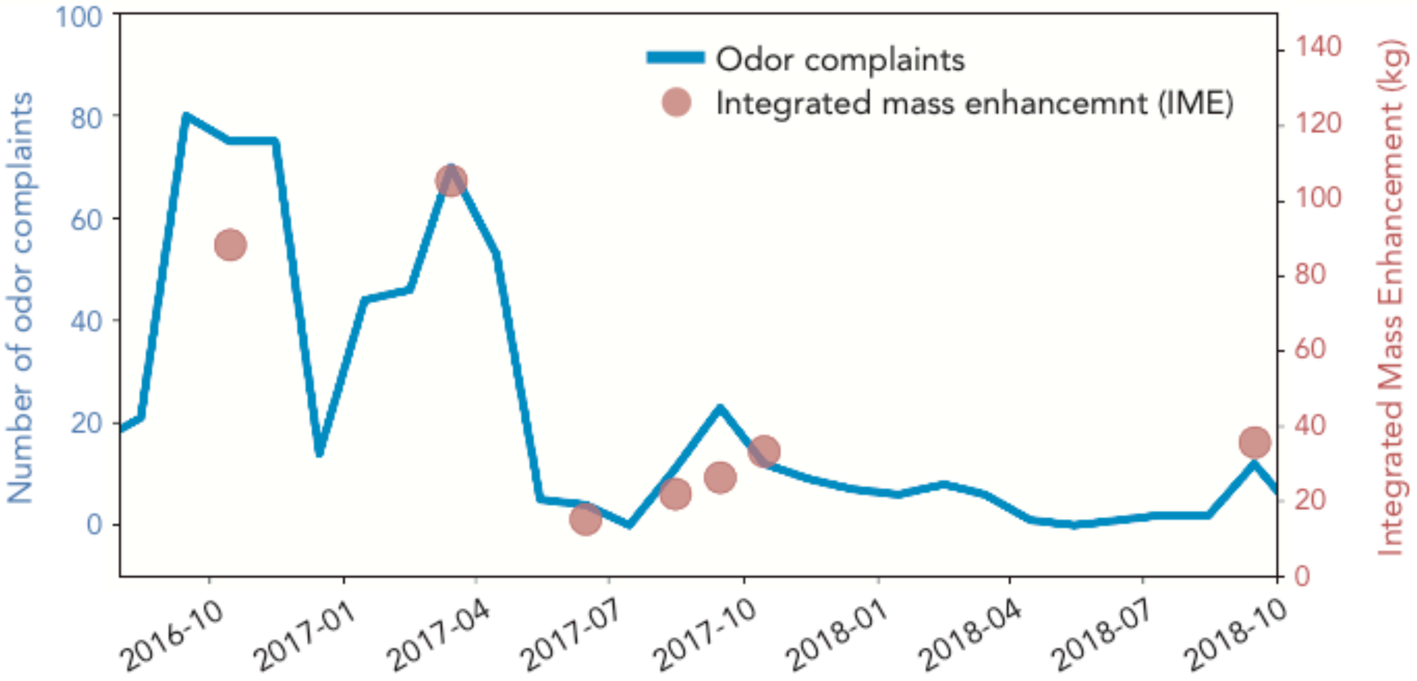
Sunshine Canyon then underwent expensive infrastructure investments to reduce these emissions.

Solution: Apply ClosureTurf (e.g., artificial grass), PosiShell (cement, bentonite, fiber spray mix), or compacted vegetative cover to problematic slopes.

Improvements were validated by AVIRIS-NG. Odor complaints were reduced as well!

Methane plumes after infrastructure improvements

Trend in intermediate slope IME and odor complaints



IME: Measure of excess methane plume mass retrieved by AVIRIS-NG

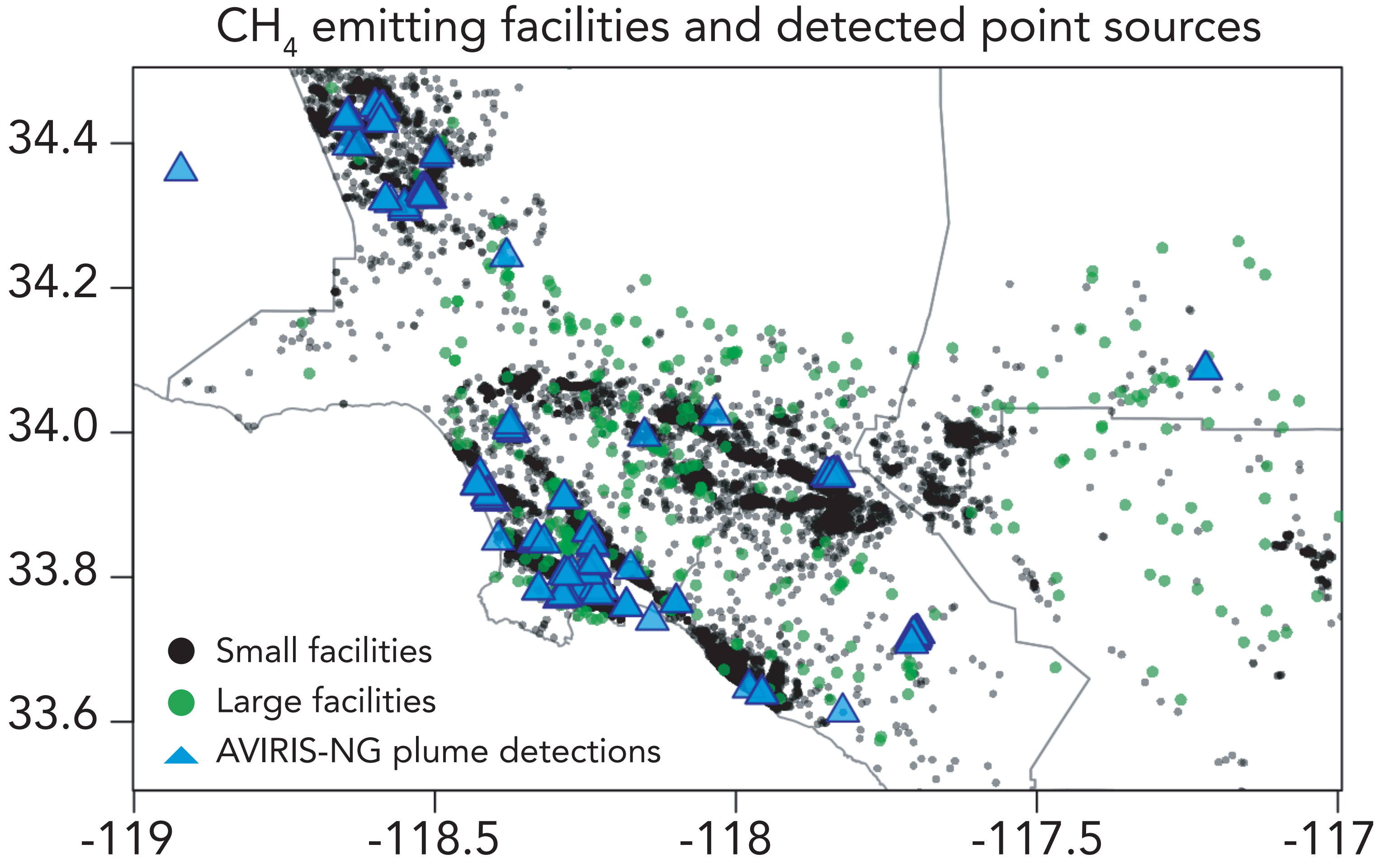
One step further:

How can I develop a theoretical surface monitoring system that will account for freely available satellite information?

- Use inversion of TROPOMI data to see where you are already getting good information about methane emitters.

- Where you aren’t getting good information, plan deployment of surface monitors around that.

Tool to help us: VISTA-LA provides geolocations and metadata about methane point sources.

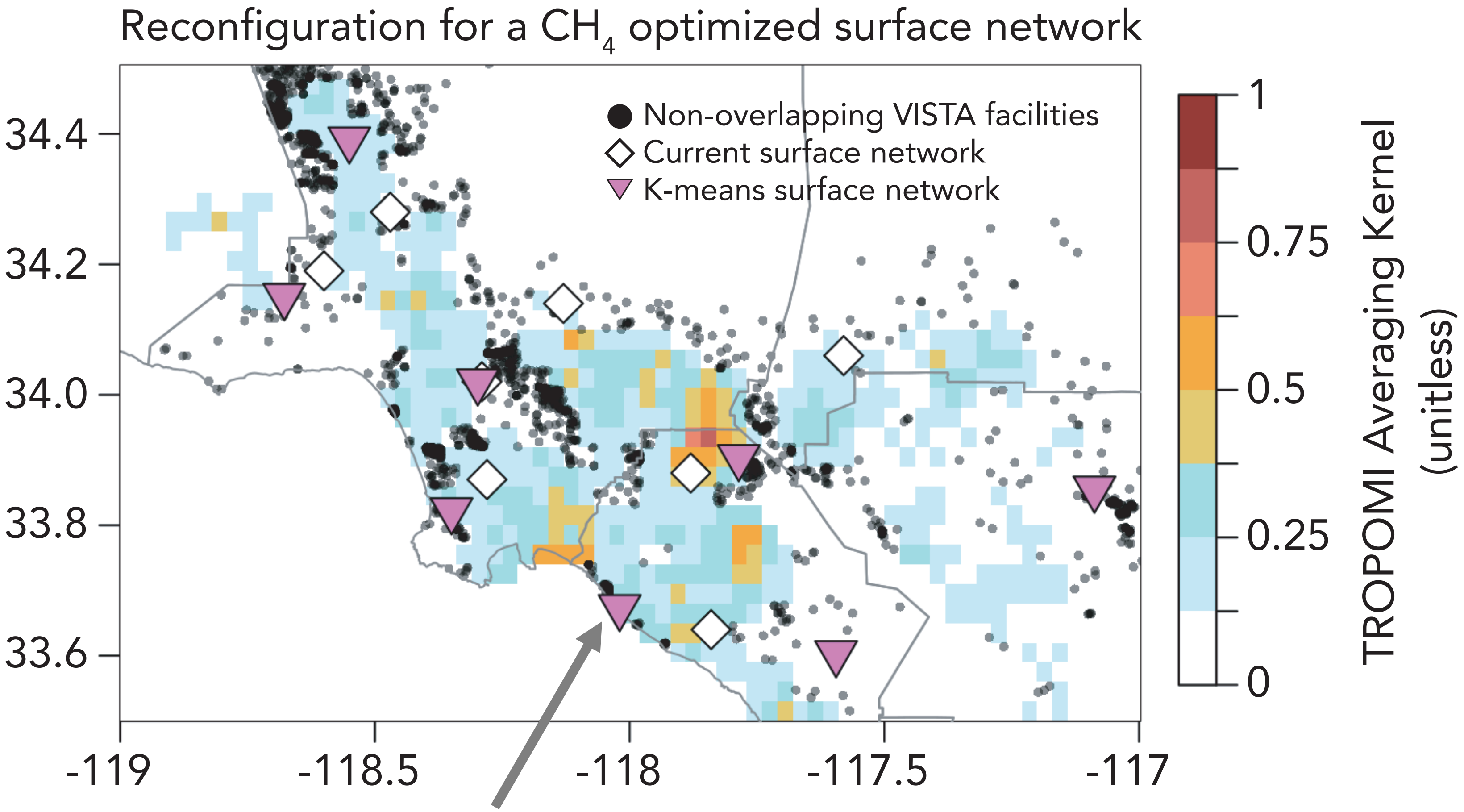


Large facilities:
Compressor stations
Landfills
oil/gas processing plants
wastewater treatment plans

Small facilities:
Oil/gas wells

Not pictured:
Pipelines

Combining VISTA-LA data with information from inversion tells us which emitters have partial constraint via space-based monitoring.



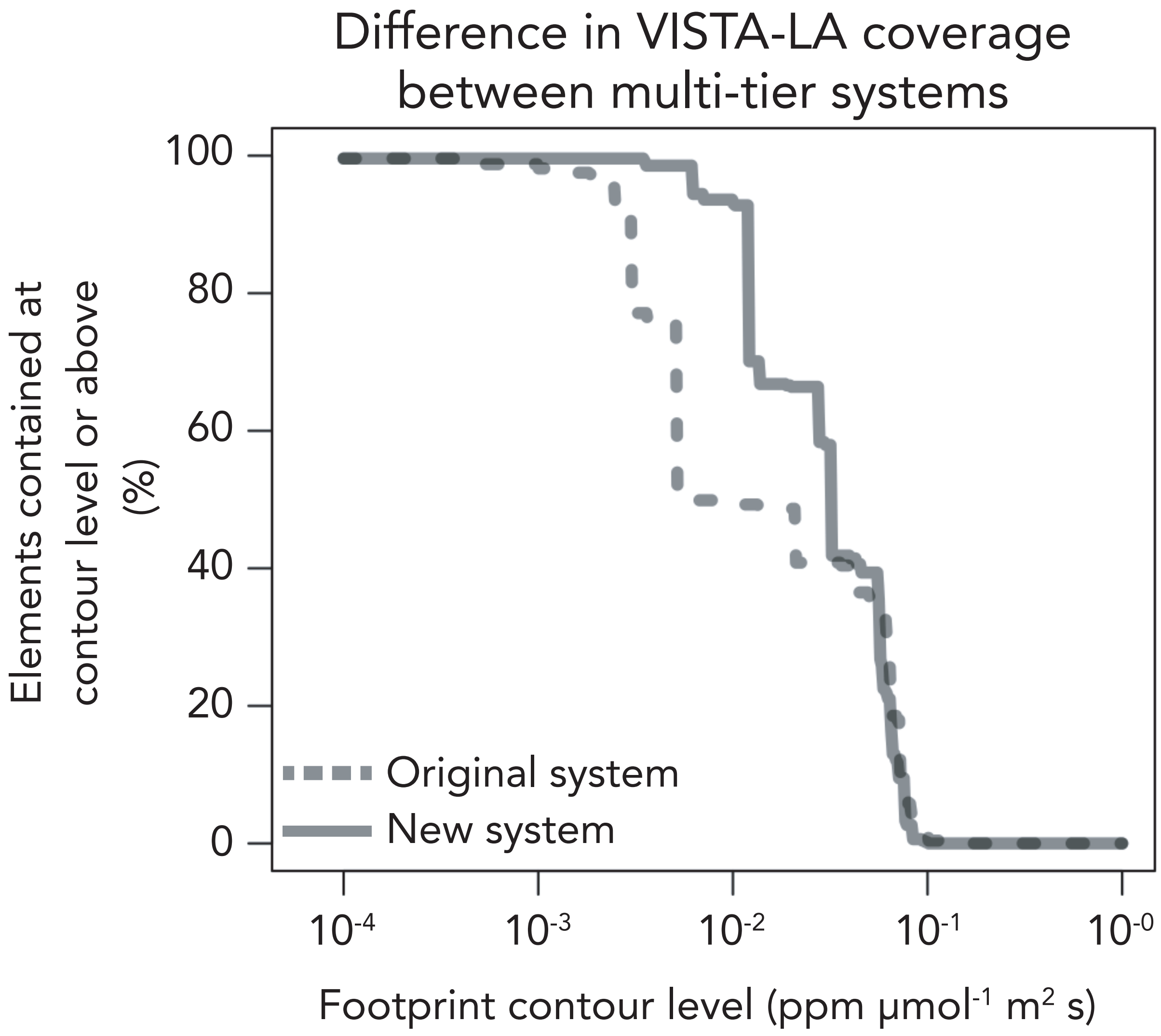
We choose new theoretical towers based on a spatial clustering of VISTA-LA elements that don't have much averaging kernel sensitivity

Reminder:

Averaging kernel tells us how much a grid cell is relying on observations or the prior in the inversion.

$$\mathbf{A} = \frac{\partial \hat{\mathbf{x}}}{\partial \mathbf{x}} = \mathbf{GH}$$

New multi-tiered system theoretically has better coverage of VISTA-LA locations that before.



Increased overlap between VISTA-LA elements at higher contour levels shows the new system more sensitive to potential methane emitters.

We can summarize our findings in a series of steps for implementing a data strategy:

Step 1: Develop a GIS database of potential methane sources.

Step 2: Simulate footprints for TROPOMI within the domain.

Step 3: Perform an atmospheric inversion using TROPOMI receptors and derive an estimate for the averaging kernel matrix **A.**

Step 4: Identify which point sources fall outside the ~0.10 threshold contours of **A**. Perform a spatial clustering algorithm for non-overlapping point sources, using as many cluster centers as surface monitors that are available for deployment.

Step 5: Perform a multi-tiered atmospheric inversion to identify methane hotspots.

Step 6: Deploy mobile or airborne monitoring around individual point sources in regions that the multi-tiered inverse identified as anomalous.

Step 7: Engage with local stakeholders to report findings and develop a mitigation strategy (e.g., Sunshine Canyon Landfill Case Study, Section 4.2).

Conclusions

- Multiple independent methane observations can be synthesized on a regional scale via a data assimilation / lagrangian transport model system.

- A multiple step strategy is proposed for creating new multi-tiered networks

- Independent AVIRIS-NG flights at Sunshine Canyon Landfill corroborated the inverse product from the multi-tiered inverse system.

- Future spaceborne imaging spectrometers will be able to detect very large methane sources.